



Full-Scale Flight Test

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Co-API
IRAC V&V and Testbeds**

**NASA Aviation Safety Program Technical Conference
Oct 2007**



Why?

The NASA Dryden Flight Research Center was named after Dr. Hugh L. Dryden, the first Deputy Administrator of NASA. The following is his explanation as to why there is a need for flight research,

“ . . . to separate the real from the imagined and to make known the overlooked and the unexpected. . . ”.





Current IRAC Flight Assets



NASA Dryden Flight Research Center Photo Collection
<http://www.dfrc.nasa.gov/Gallery/Photo/index.html>
NASA Photo: EC03-0039-1 Date: February 7, 2003 Photo By: Jim Ross

NASA Dryden's highly-modified Active Aeroelastic Wing F/A-18A shows off its form during a 360-degree aileron roll during a research flight.

F/A-18 853 (in development)
Flight validated sim
68040 RFCS
HIL test bench



NASA Dryden Flight Research Center Photo Collection
<http://www.dfrc.nasa.gov/Gallery/Photo/index.html>
NASA Photo: EC03-0311-05 Date: December 4, 2003 Photo By: Jim Ross

C-17 in flight over Rogers Dry lakebed

C-17 T1 (USAF asset)
Primarily engine instrumentation



Dryden Flight Research Center EC96-43780-1 Photographed 10/96
Striking Silhouette: F-15B Advanced Control Technology for Integrated Vehicles (ACTIVE) research program. NASA photo by Jim Ross

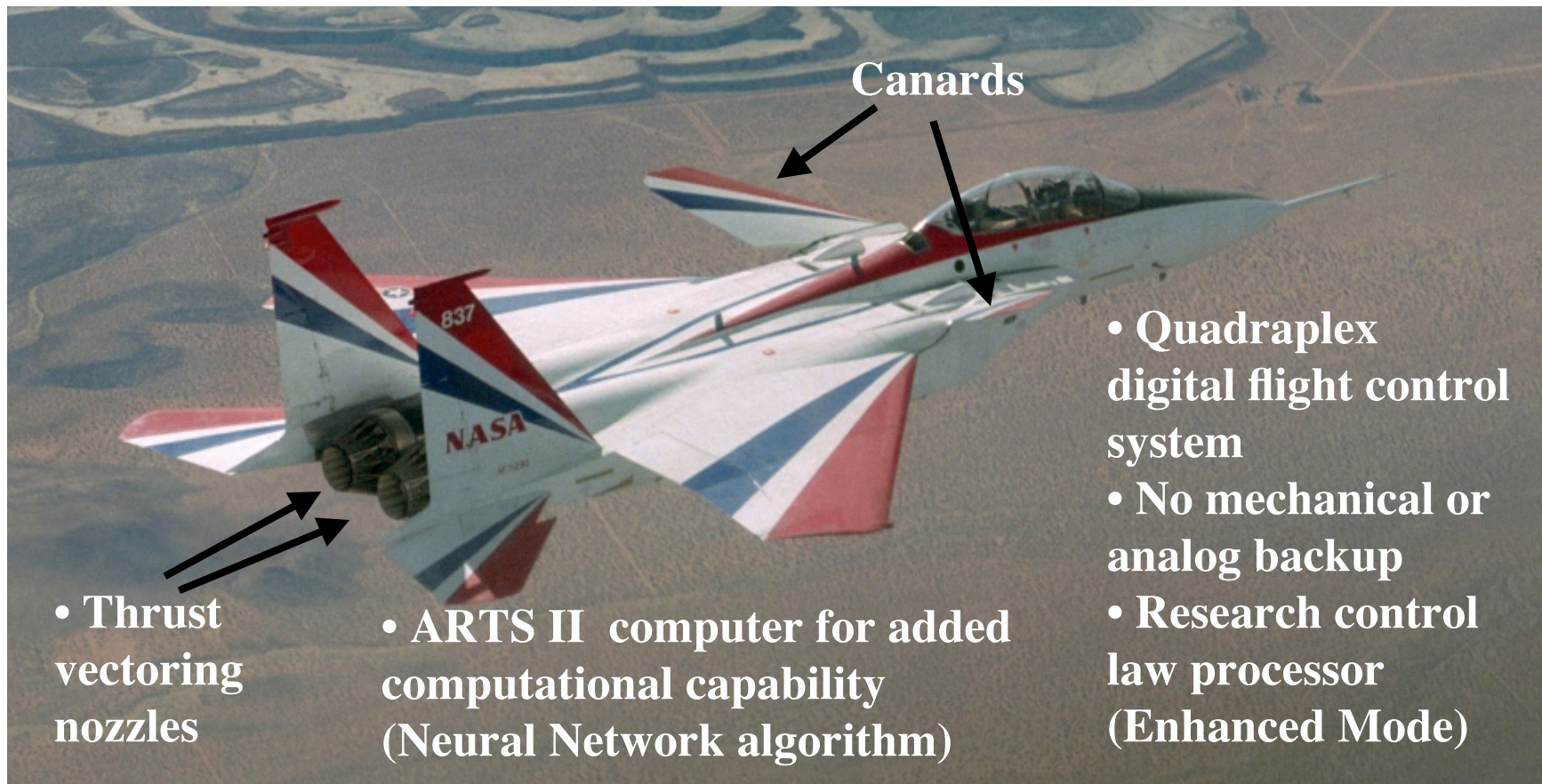
F-15 837
Flight validated sim
68040 enhanced mode
ARTS II
HIL at Boeing





NASA NF-15B Tail Number 837

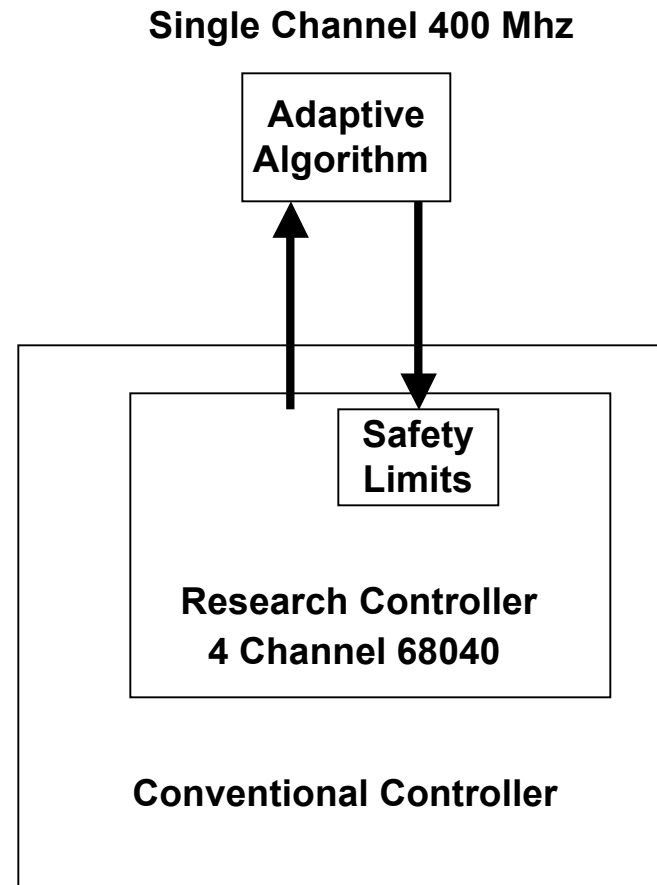
Extensively modified F-15 airframe





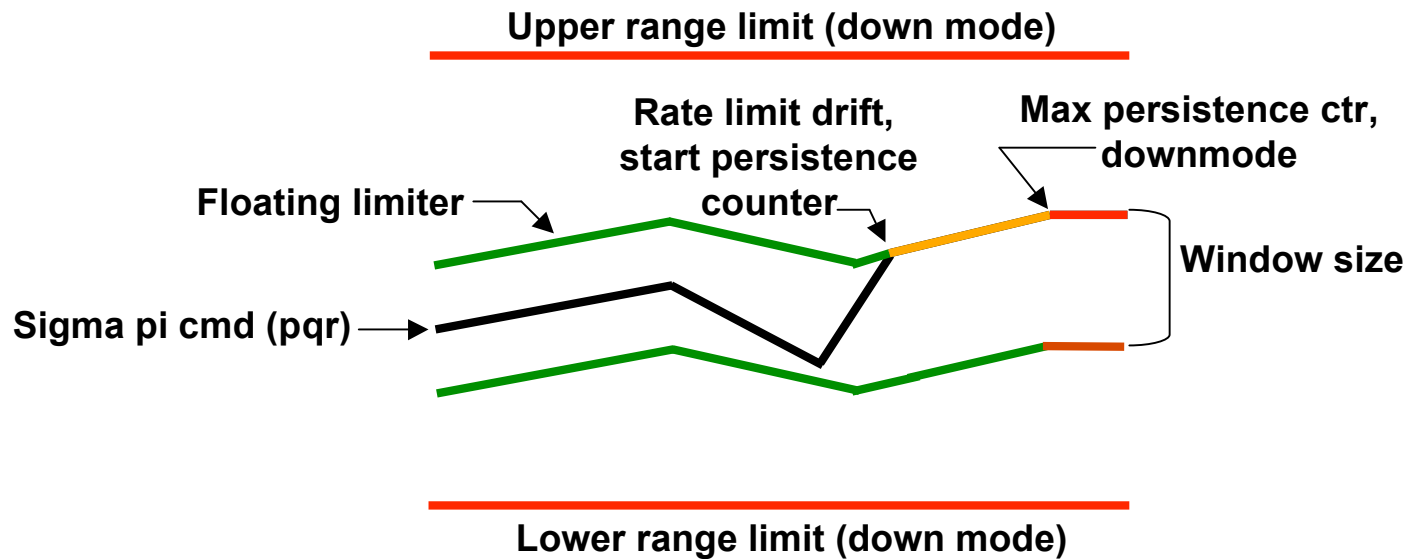
Limited Authority System

- **Adaptation algorithm implemented in separate processor**
 - Class B software
 - Autocoded directly from Simulink block diagram
 - Many configurable settings
 - Learning rates
 - Weight limits
 - Thresholds, etc.
- **Control laws programmed in Class A, quad-redundant system**
- **Protection provided by floating limiter on adaptation signals**





NN Floating Limiter



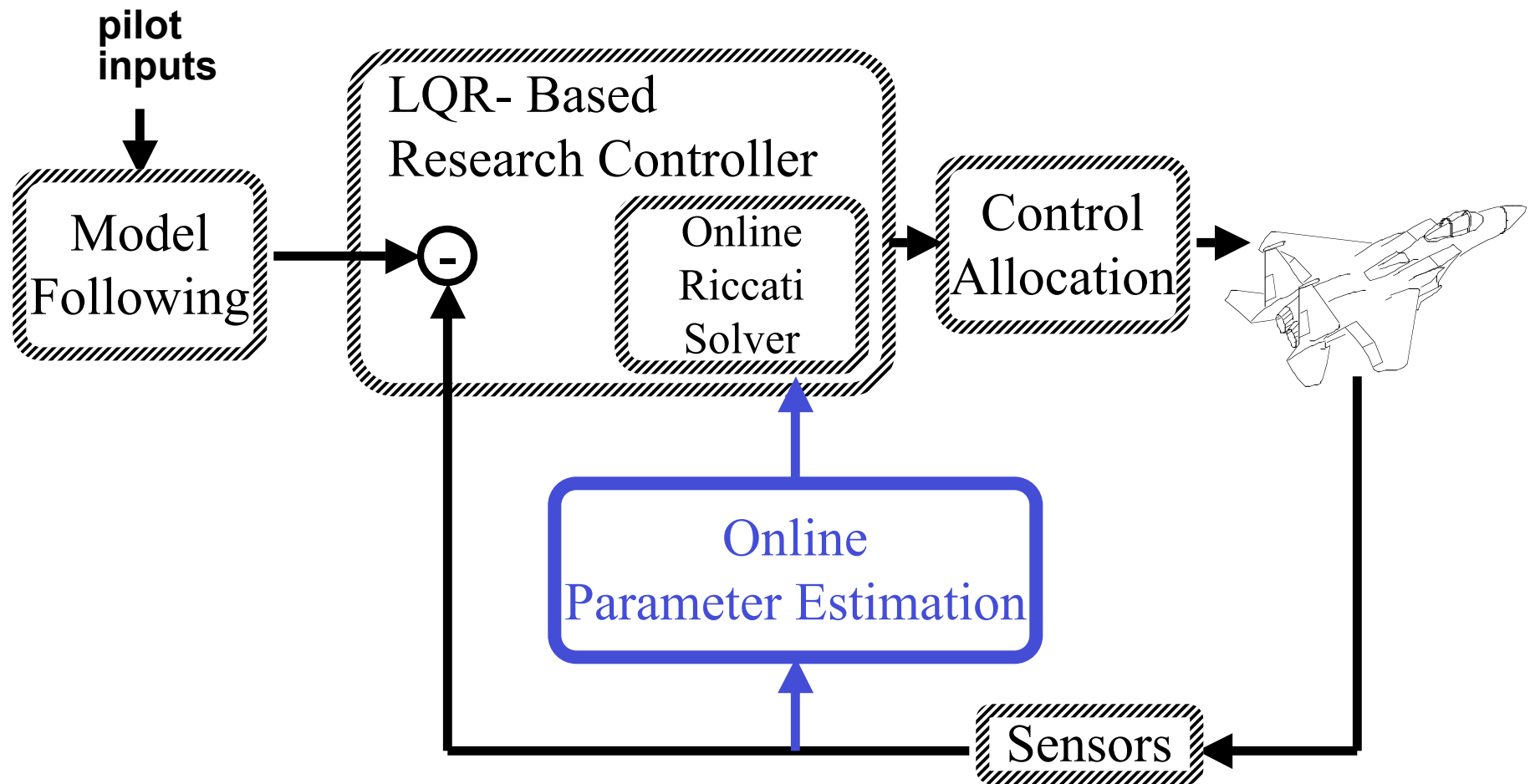
Black – sigma pi cmd
Green – floating limiter boundary
Orange – limited command (fl_drift_flag)
Red – down mode condition (fl_dmode_flag)

Tunable metrics
Window delta
Drift rate
Persistence limiter
Range limits



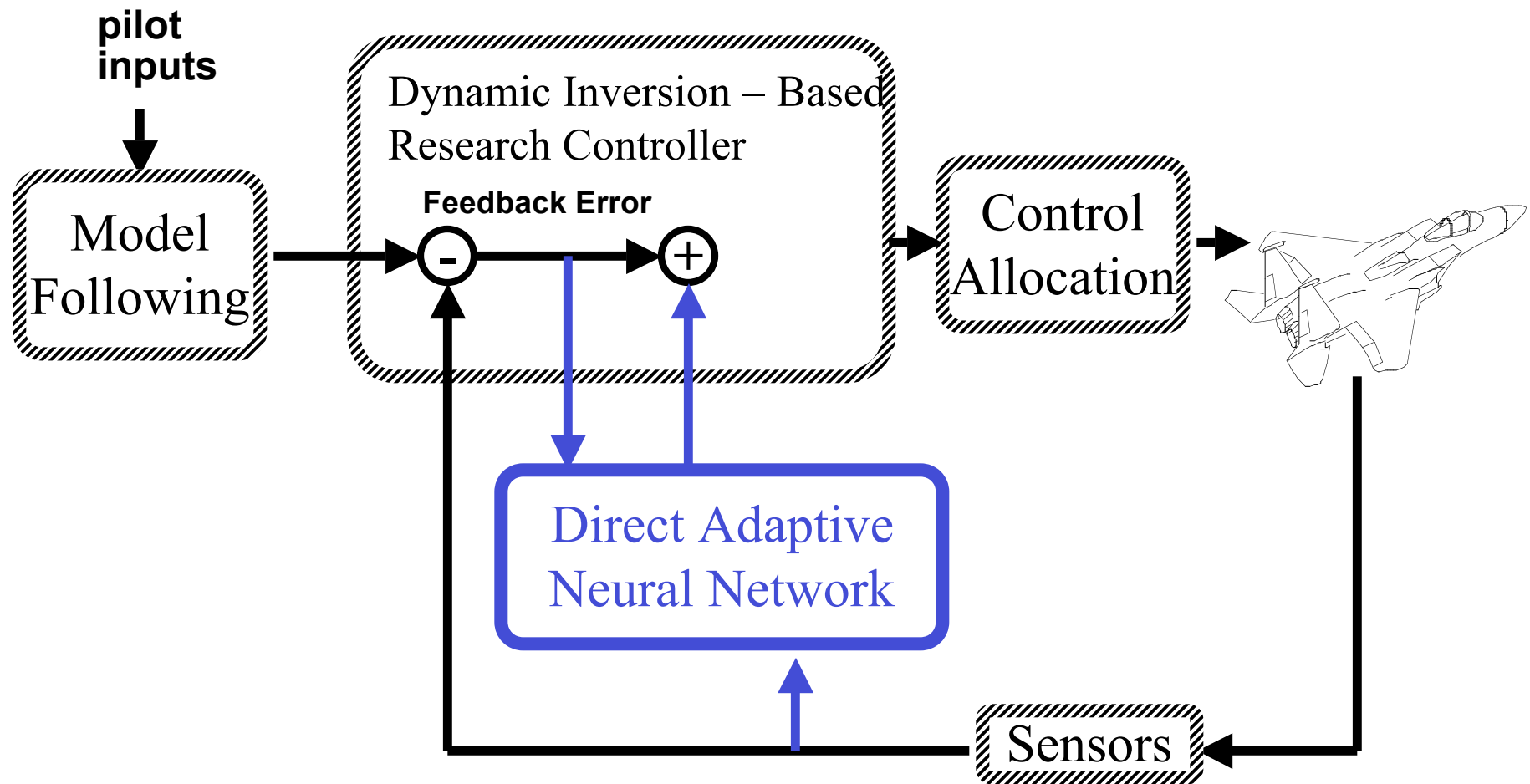


Gen I Indirect **Adaptive** Control Architecture





Gen II Direct Adaptive Control Architecture





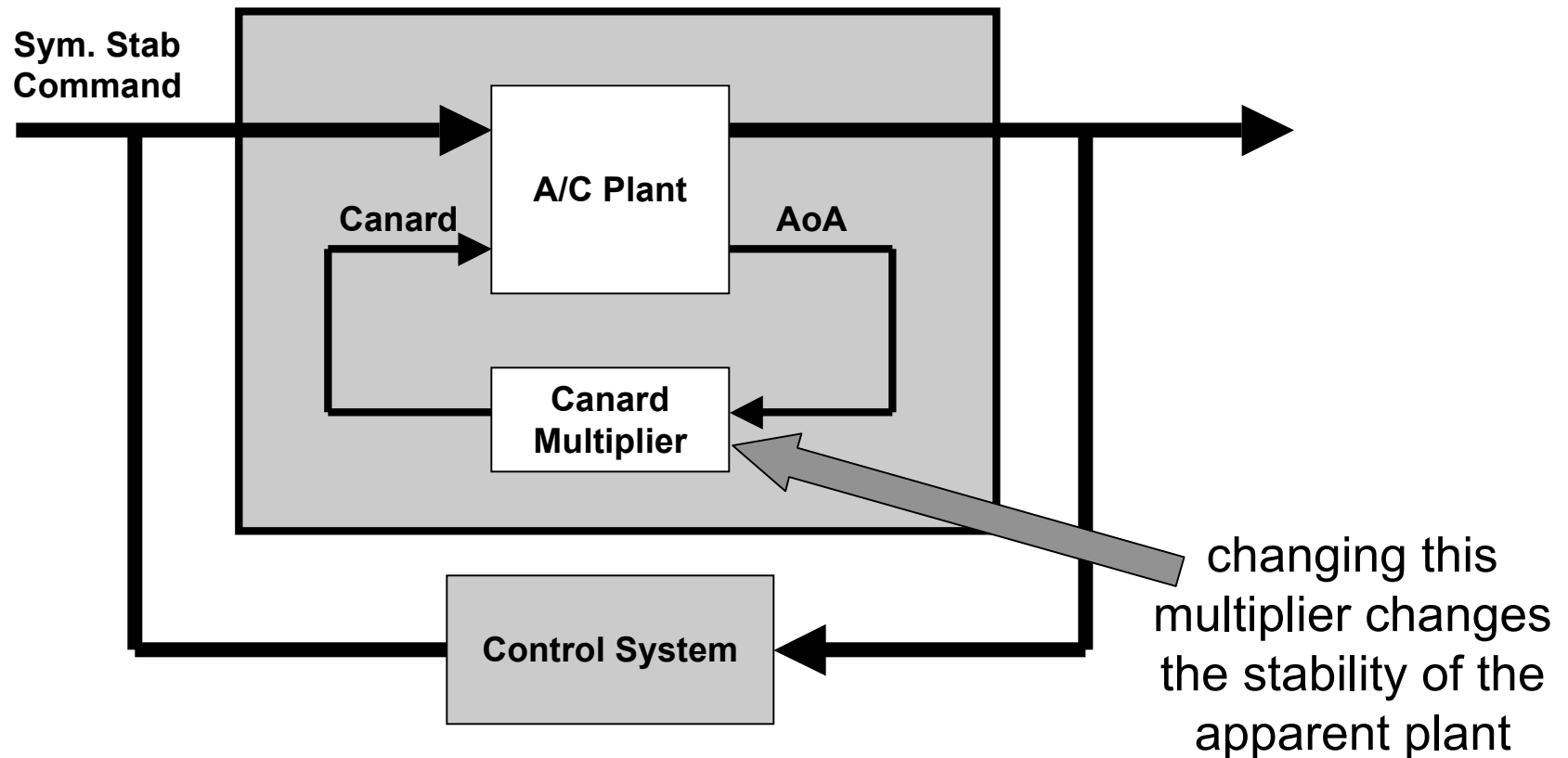
Simulated Destabilization A-Matrix Failure





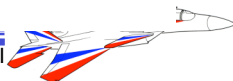
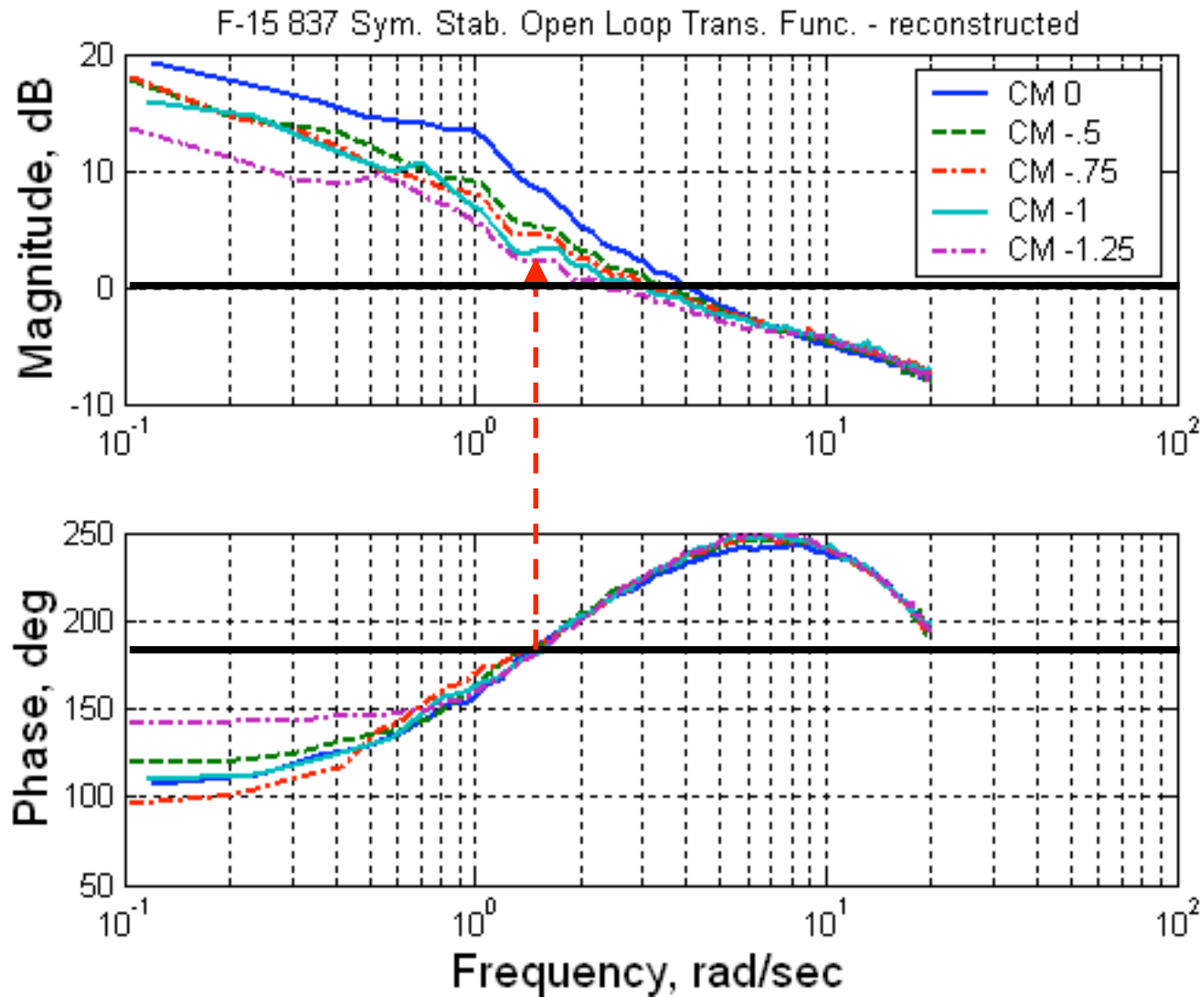
Canard Multiplier – “An A-Matrix Failure”

Apparent Longitudinal Plant





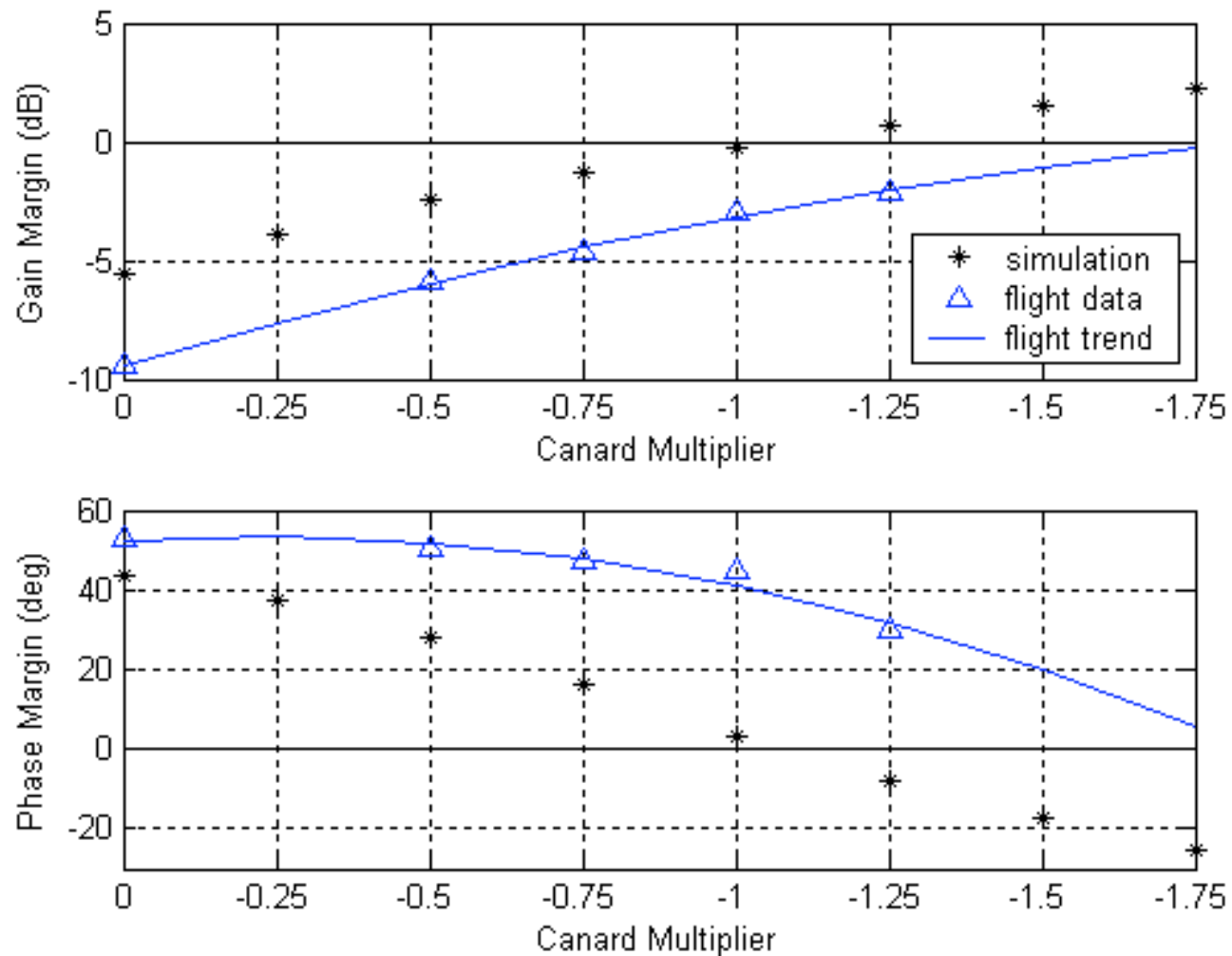
Flight Results – Failure with No Adaptation





Stability Margin Trends

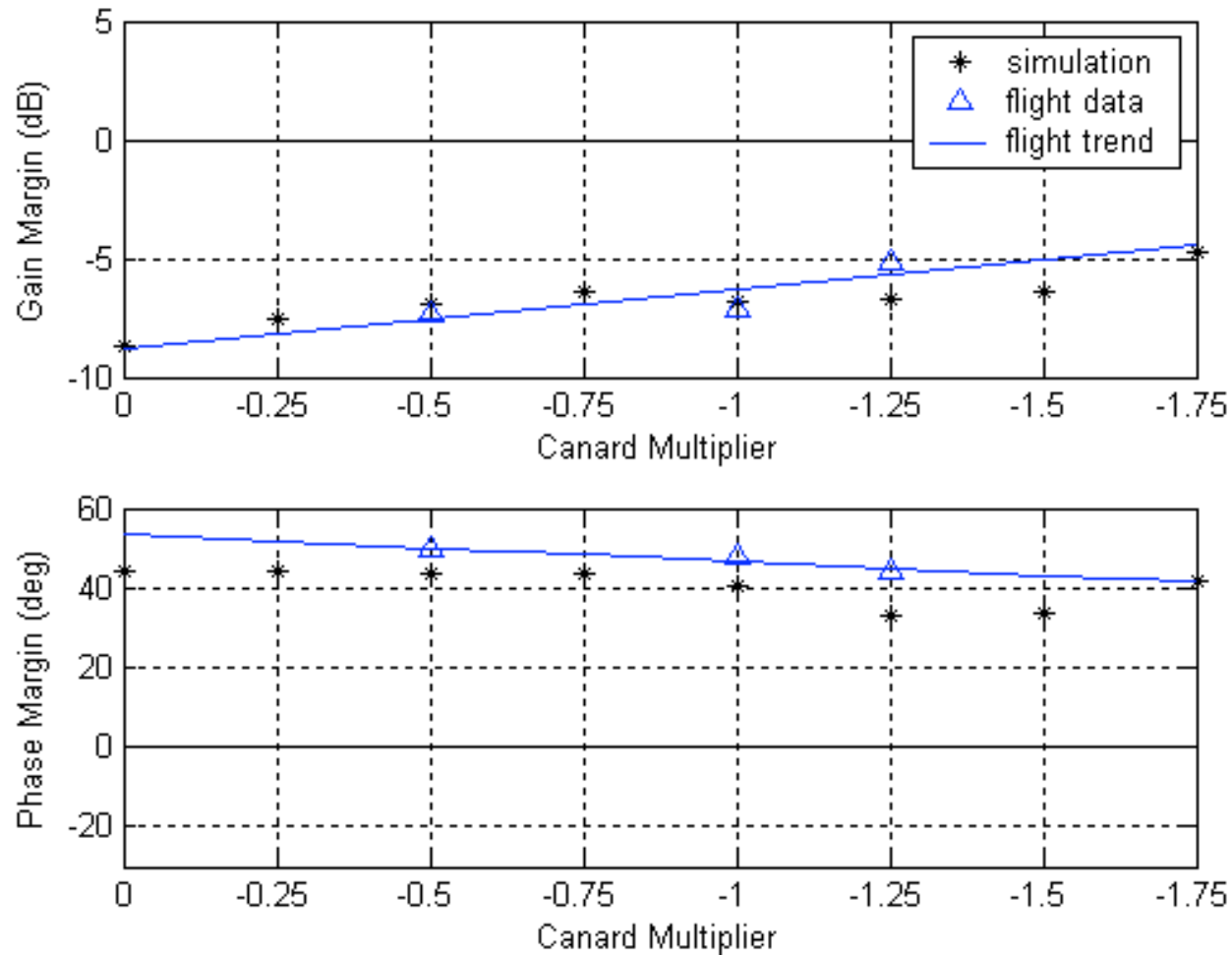
Symmetric Stab Loop, NN Off





Stability Margin Trends

Symmetric Stab Loop, NN On





Frozen Stabilator B-Matrix Failure





Simulated Stabilator Failure

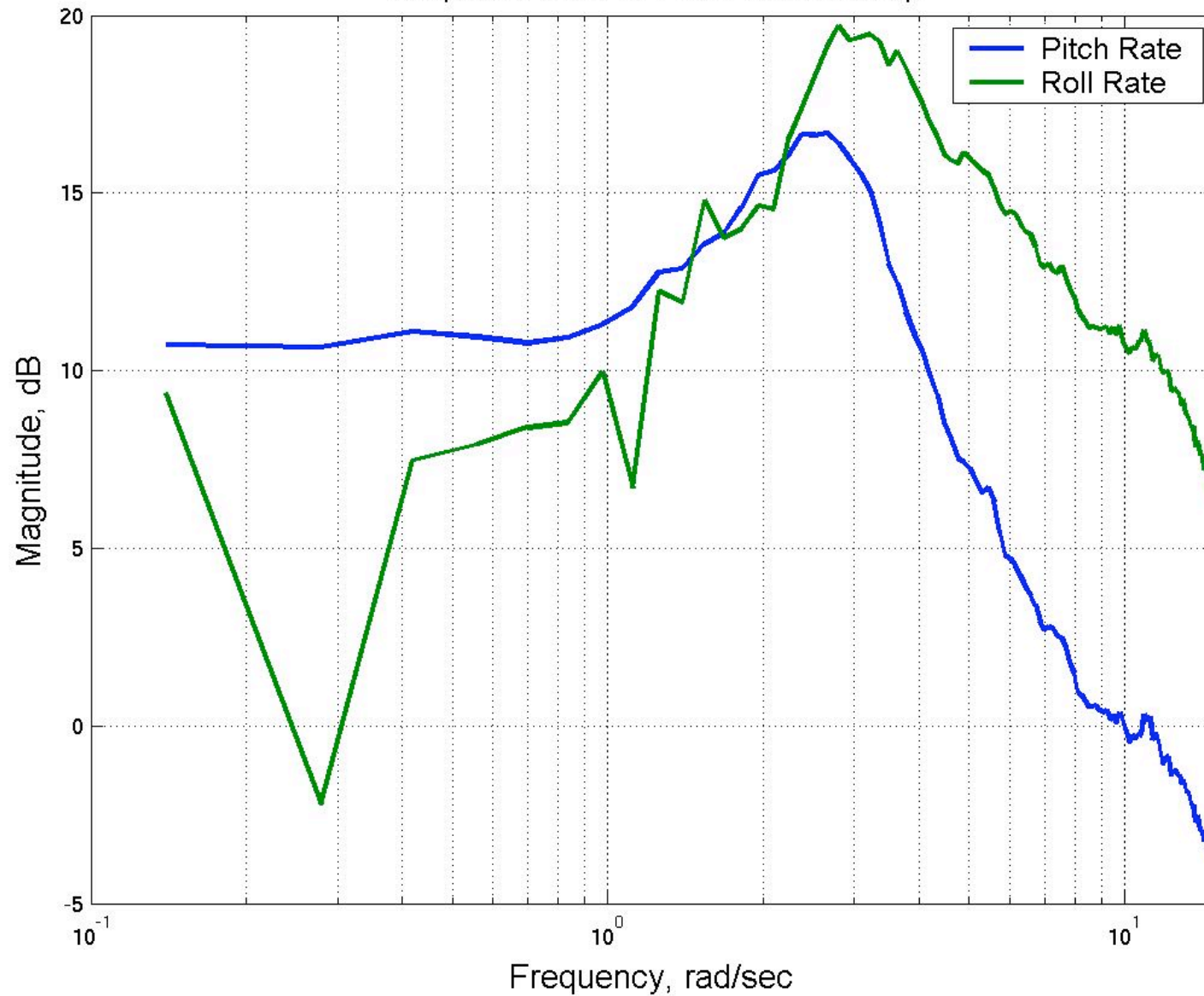




Flight Results

Simulated Frozen Stabilator

Response Due To Pitch Stick Sweep



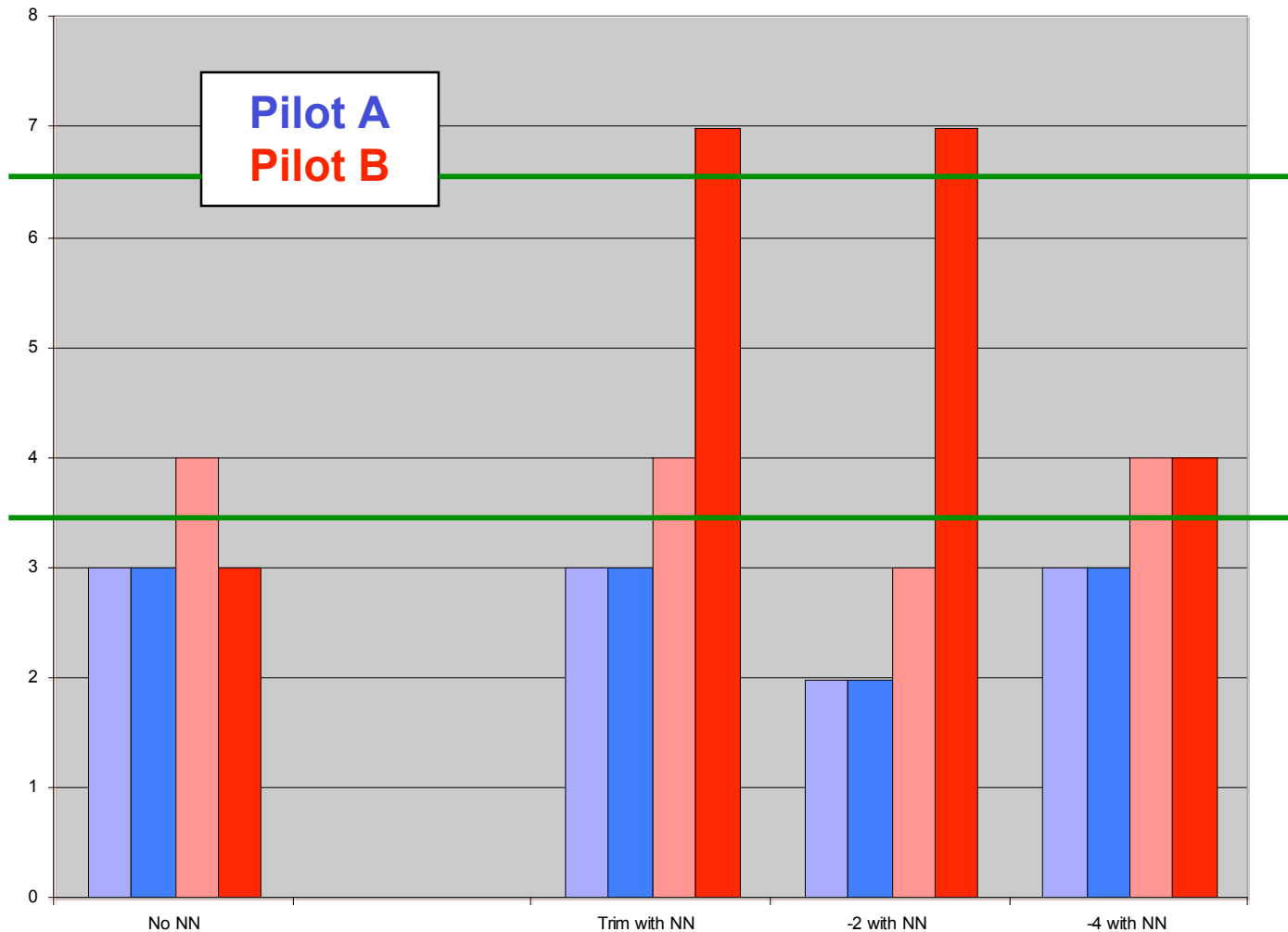


Pilot Ratings with Adaptation Formation Flight Task

CHR

Level II

Level I



No NN

Trim

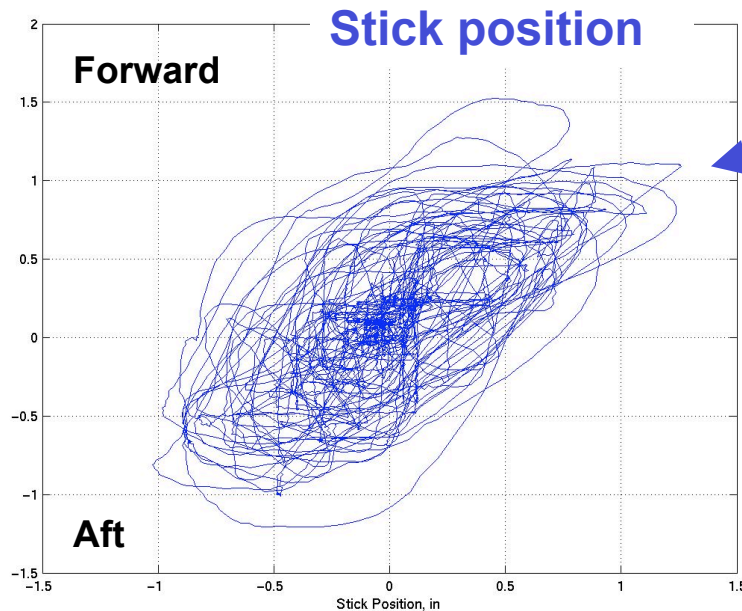
-2

-4



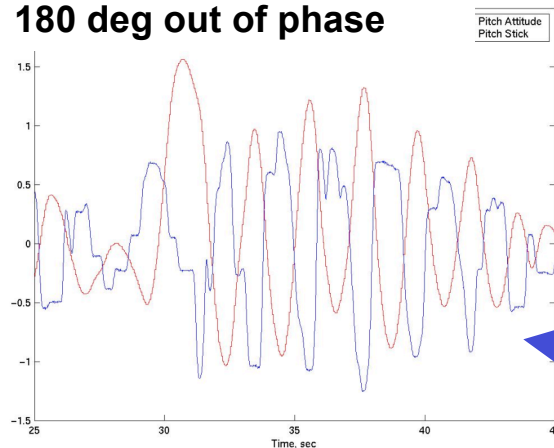


Simulated Frozen Stabilator



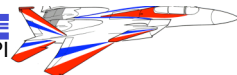
- Pilot unconsciously compensates for asymmetry
- Correlated pilot input presents greater challenge for adaptive system

180 deg out of phase



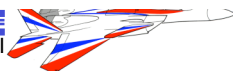
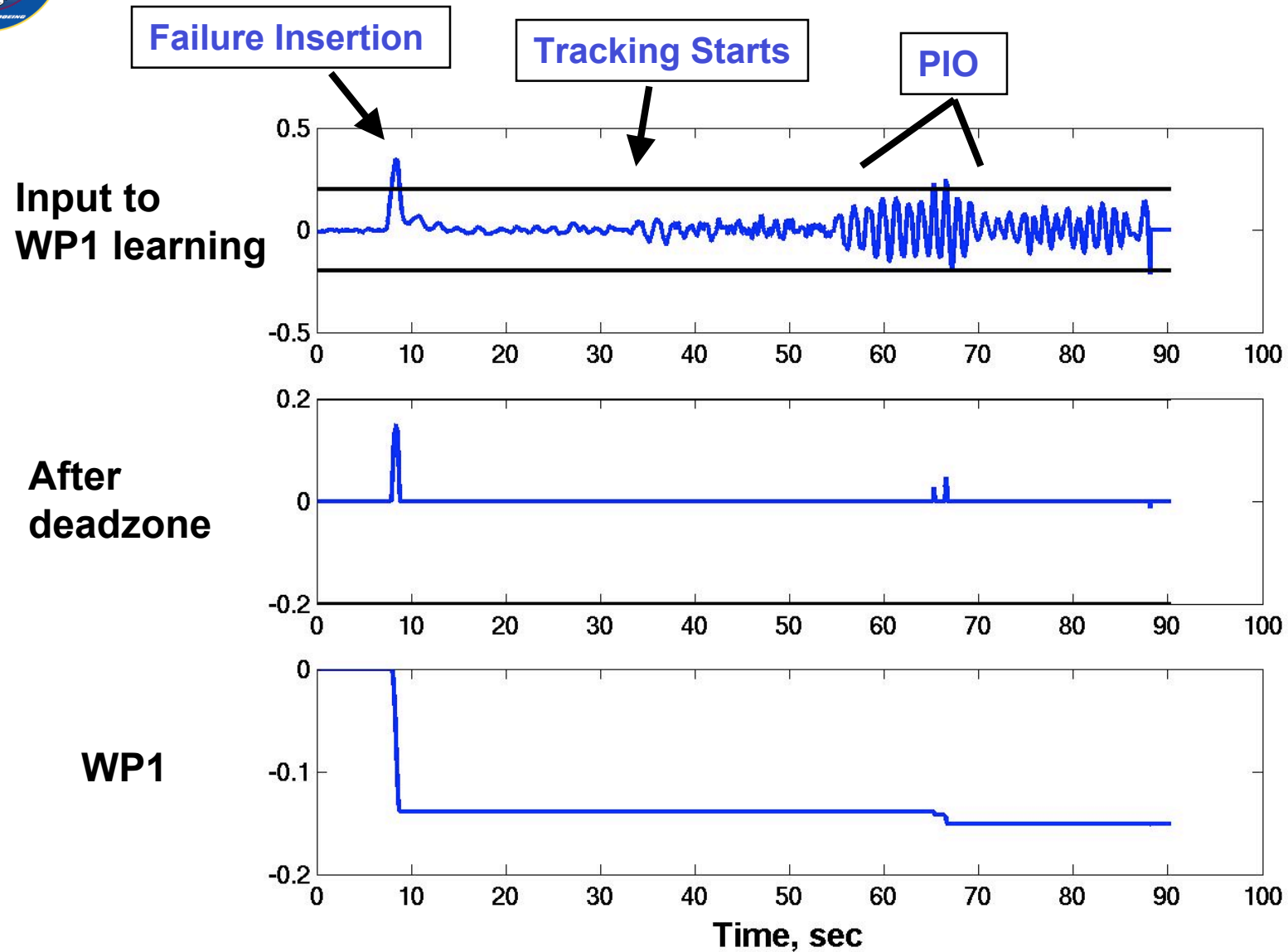
+ Adaptive system reduced the amount of cross coupling

- Adaptive system also introduced tendency for pilot induced oscillations (PIO)





Deadzone Effect





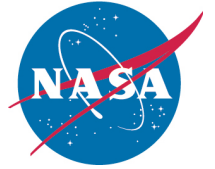
F-15 837 Summary

- **Adaptive system generally behaved as predicted**
 - Weights adjusted in correct direction
 - Real world turbulence and measurement noise did not adversely affect learning
 - Only safety disengagements observed were due to very aggressive pilot inputs
- **Simulated destabilization less than predicted**
 - Flight vehicle more stable than aero model predicts
 - Software change in work to increase destabilizing gain
- **Adaptation to frozen stabilator introduced PIO tendency**
 - Interesting interaction between pilot adaptation and system adaptation
 - Working on an improved neural network





NASA F/A-18 Tail Number 853



- Quad 68040 Research Flight Control System with production control system as backup
- Extensively instrumented for flight loads
- Wing deflection measurement system
- Faster, more capable RFCS in work

Future adaptive research areas:

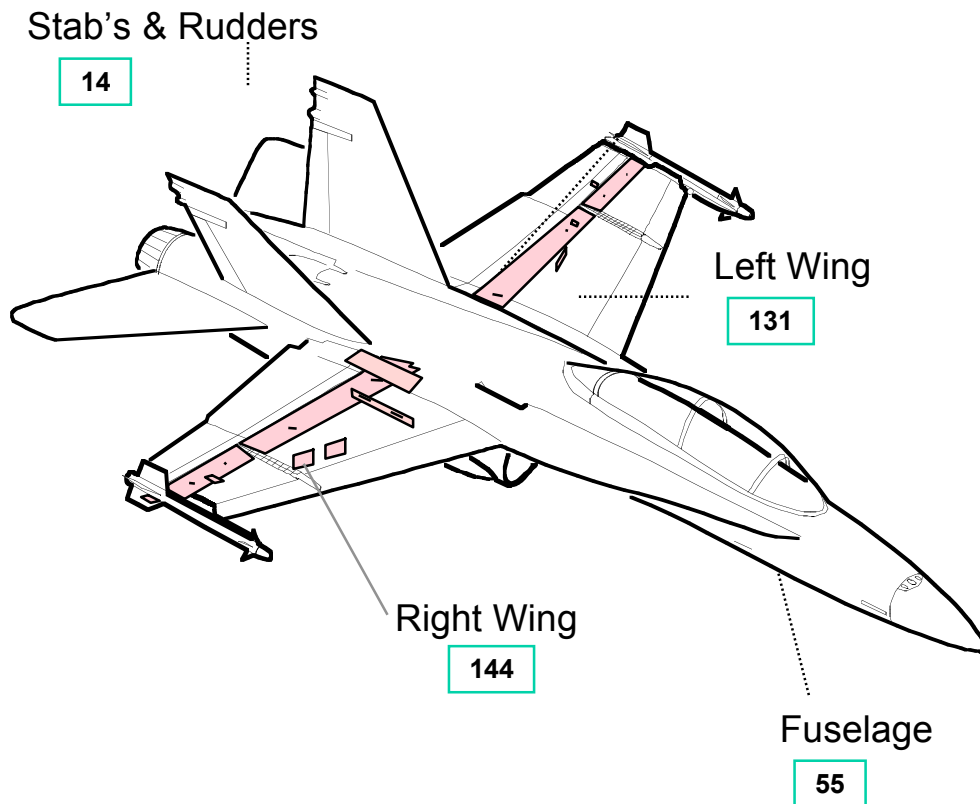
- Implementing adaptive control algorithms in a multi-processor redundant system
- Adaptively augmenting control by integrating propulsion control
- Assessing integrated adaptive flight management and planning
- Automatically sensing and suppressing aeroservoelastic (ASE) interactions
- Integration of static structural load measurements with adaptive controller





F/A-18 853 INSTRUMENTATION - SENSORS

- Sensor by location



RH WING PARAMETERS-144

106 - FULL BRIDGE STRAIN GAGES
18 - ACCELEROMETERS
8 - POSITION SENSORS
10 - VOLTAGE SENSORS
1 - TEMPERATURE SENSORS

LH WING PARAMETERS-131

76 - FULL BRIDGE STRAIN GAGES
18 - ACCELEROMETERS
8 - POSITION SENSORS
10 - VOLTAGE SENSORS
2 - TEMPERATURE SENSORS
16 - FDMS TARGETS

FUSELAGE PARAMETERS-55

6 - MOTION PAK
7 - ACCELEROMETERS
7 - TEMPERATURES
8 - FUEL QUANTITY
27 - MISC. PARAMETERS

EMPENAGE PARAMETERS-14

4 - POSITIONS SENSORS
10 - ACCELEROMETERS

A/C 1553 DATA BUS - 1092

GPS/INS 1553 DATA BUS - 170

TOTAL PARAMETERS - 1604



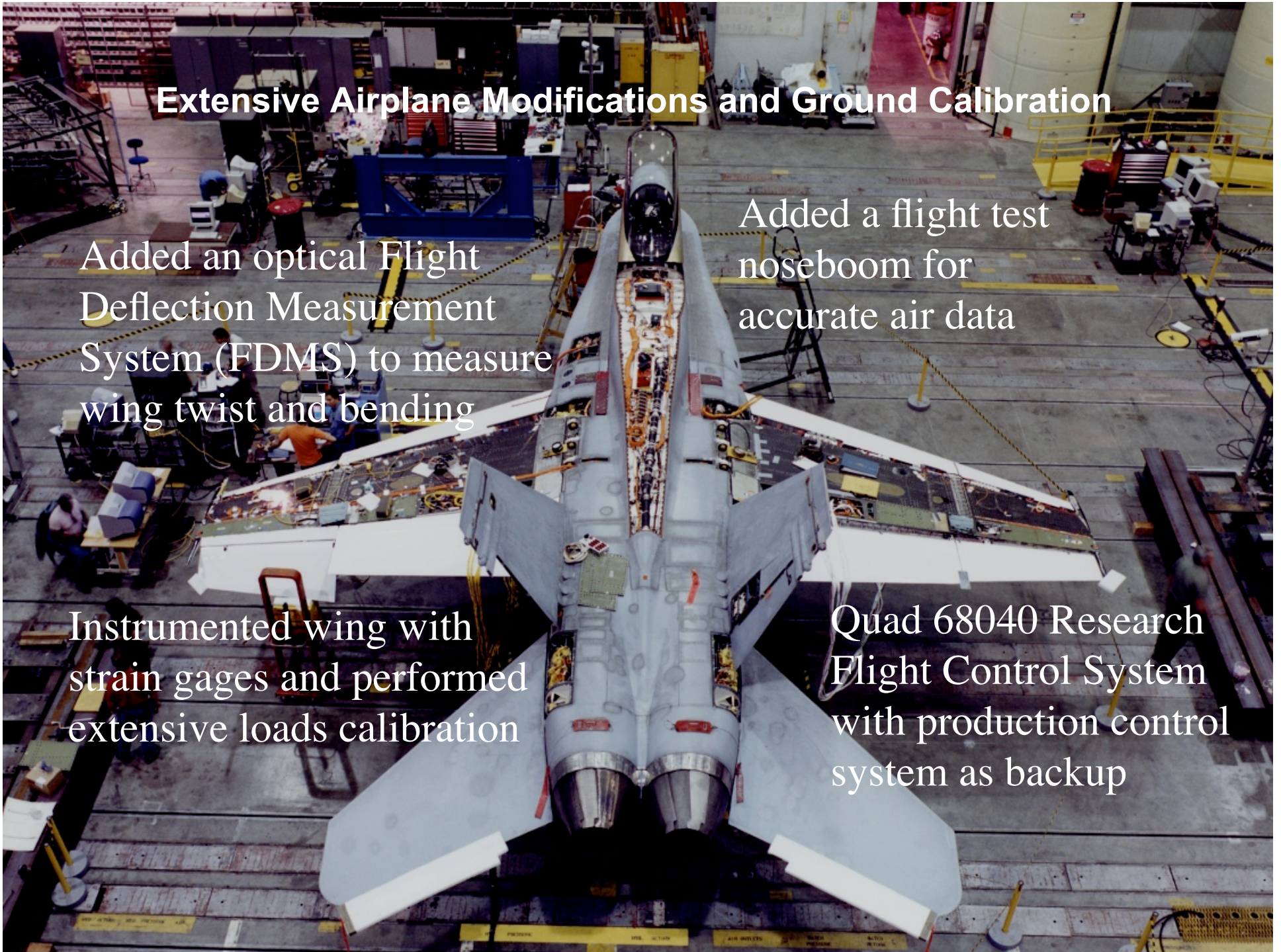
Extensive Airplane Modifications and Ground Calibration

Added an optical Flight Deflection Measurement System (FDMS) to measure wing twist and bending

Added a flight test noseboom for accurate air data

Instrumented wing with strain gages and performed extensive loads calibration

Quad 68040 Research Flight Control System with production control system as backup

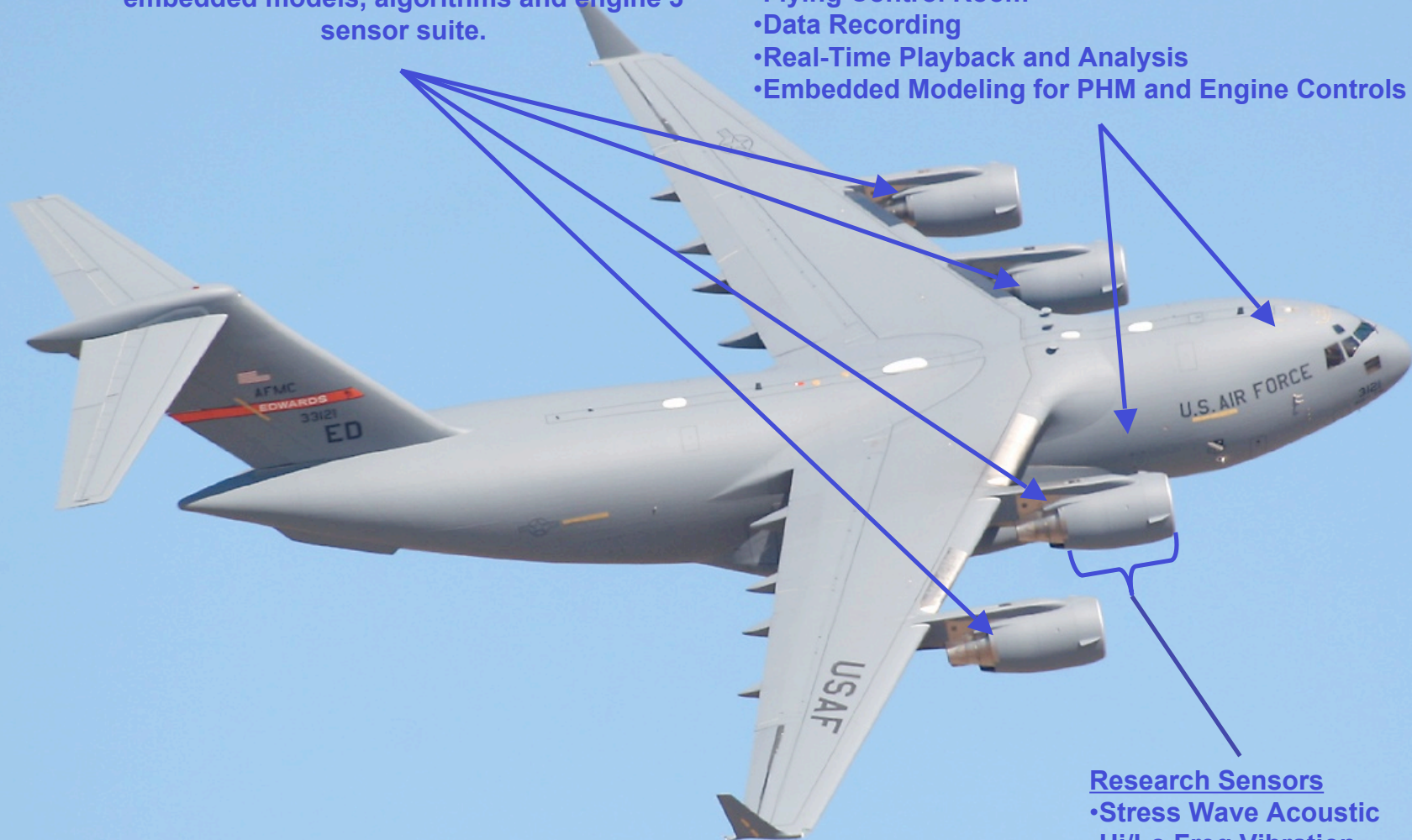




Able to couple all four commercial type engines to data system for research against embedded models, algorithms and engine 3 sensor suite.

Onboard Instrumentation Pallet and Research Stations

- Flying Control Room
- Data Recording
- Real-Time Playback and Analysis
- Embedded Modeling for PHM and Engine Controls



Research Sensors

- Stress Wave Acoustic
- Hi/Lo Freq Vibration
- Inlet/Exhaust Gas Path
- Oil Health
- Certification Suite

Upgrades In Work

- Downlink for real-time web based interface
- Additional PHM sensor/components/hardware to be installed



Conclusions

- **Full scale flight test forces designers to address real-world issues**
- **Provides high-visibility demonstration**
- **Adds credibility that adaptation technology can be a viable design option**
- **Helps to “separate the real from the imagined”**





Potential Future Work

- **How to sense and incorporate structural limitations into the adaptive algorithm**
- **Develop better metrics – What is most important to ensure that a damaged vehicle can be safely landed?**
- **Investigate adaptive notch filters to avoid adverse aero-servo-elastic (ASE) interactions**
- **Develop and validate requirements for the use of propulsive control for failure / damage conditions**
- **Maintain long-term effort to advance adaptive control technology**





Questions?

